Geographic Information Systems in Water Resources Spatial Analysis Exercise CUAHSI Virtual University, 2019 David Tarboton

Goal

The goal of this exercise is to serve as an introduction to Spatial Analysis with ArcGIS.

Objectives

- Use ArcGIS.com services to access and extract elevation data
- Interpolate data values at points to create a spatial field to use in hydrologic calculations. Use this to calculate watershed area average precipitation
- Use raster data and raster calculator functionality to calculate watershed attributes such as mean elevation, mean annual precipitation and runoff ratio.

Computer and Data Requirements

To carry out this exercise, you need to have a computer, which runs ArcGIS Pro. The necessary data are provided in the accompanying zip file, **SpatialAnalysisData.zip**.

Overview

The purpose of this part of the exercise is to calculate average watershed elevation for subwatersheds of the Little Bear-Logan subbasin, and to calculate average precipitation over each of these subwatersheds using different interpolation methods. Average precipitation is then converted to a volume of precipitation and compared to runoff volumes using a runoff ratio. This provides an insight into the annual water balance of these watersheds, namely what fraction of precipitation is streamflow and what fraction is lost to evapotranspiration and other losses such as infiltration and groundwater recharge.

Data

The following data is provided in the **SpatialAnalysisData.zip** file:

BasemapExercise.gdb file Geodatabase from BasemapExercise.

- 🔺 🗟 BasemapExercise.gdb
 - 🔺 🔁 LittleBearLogan
 - 🗄 Flowlines
 - Gages
 - Subwatersheds
 - 🖾 Watershed

LittleBearLoganAnnPrecip.csv. Sites in and around Little Bear Logan Watershed where precipitation has been measured and data is available in the Global Historical Climatology Network (GHCN). T

AssembleGHCNData.R, monthprecip.csv, monthdaycount.csv. R script and intermediate files used in preparing the data as described in Appendix. You only need to use these if you want to apply or adapt this approach to another area or look into the data more deeply.

1. Loading the Data

Open ArcGIS Pro and create a new Map project, SpatialAnalysisExercise

Create a New Project	×
Name SpatialAnalysisExercise	
Location C:\Users\dtarb\Documents\ArcGISWork	a
\checkmark Create a new folder for this project	
	OK Cancel

Copy the file **SpatialAnalysisData.zip** into the project folder created and unzip it.

Click **Connections** in the **Insert** tab and select **Add Database** to add the **BasemapExercise.gdb** to the project. This is another way to associate a Geodatabase with a project.

PROJECT MAP INSERT AN	Select Existing Geodatabase	3
Import Map Import Map Map Connections Add Database New File Geodatabase New Database Connection	 () → ()	P Type Folder File Ger File Ger
	Name BasemapExercise.gdb Databases	Cancel

In the Catalog pane Expand BasemapExercise.gdb to see

🔺 🛜 Databases	
Epstein Spatial Analysis Exercise.gdb	
BasemapExercise.gdb	
▲ C LittleBearLogan	
- Flowlines	
Gages	
Subwatersheds	
🖾 Watershed	
Right click on the LittleBearLogan featu	re dataset and "Add To Current Map".

▲ 🛜 Databases
E SpatialAnalysisExercise.gdb
BasemapExercise.gdb
LittlePearLogan Fit Add To Current Map
Ga Add To Current Map
Sul Add data to the active map.
Wa

You should obtain a map with all these features added. Note I changed the symbology a bit.



If you right-click on one these feature classes in the map legend, select **Properties** and **Source** and scroll down until you see **Spatial Reference** at the bottom of the layer properties, you'll see that they have the **NAD 1983 UTM Zone 12N** coordinate system. You should also see that the Linear Unit is meters.

Layer Properties: Wate	ershed		×
General	Vertical Units M	leter	A
Metadata	vention on to		
Source	> Extent		
Elevation	✓ Spatial Reference		
Selection	Projected Coordinate System	NAD 1983 UTM Zone 12N	
Display	Projection	Transverse Mercator	
Cache	WKID	26912	
Definition Query	Authority	EPSG	
Time	Linear Unit	Meters (1.0)	
Range	False Easting	500000.0	
Indexes	False Northing	0.0	
Joins	Central Meridian	-111.0	
Relates	Scale Factor	0.9996	
Page Query	Latitude Of Origin	0.0	Ŧ
			OK Cancel

If you move the cursor around on the map, you may see that the coordinates at the bottom are in also in meters. When the data was added to the Map, its properties switched to that of the data being added.

Go to <u>https://livingatlas.arcgis.com/</u> and search for 'elevation'. You should see that one of the first entries is 'Ground Surface Elevation 30 m' and if you read about this you see that this is 30m raster data extracted from the USGS's National Elevation Dataset. We will use this DEM in this exercise, but loading it directly from ArcPro.

Select Add Data to the Map



And among the options presented, select **Living Atlas.** In the **Search Portal: Living Atlas** type in **elevation** and among the options presented, select **Ground Surface Elevation 30 m**, the DEM identified in the web search.

Add Data		×
€) ⑦ 💽 « Search Result	is for 'elevati 🕨 🔻 🕐 elevation	× ·
Organize 🔻 New Item 🔻		🗘 📶 Categories 👻
Folders 🔺	Name	Type 💧
🔺 🙆 Portal	飅 Terrain: Elevation Tinted Hillshade	Imager
A My Content	I Terrain	Imager
😪 Groups	🔳 Ground Surface Elevation - 30m	lmager
🛆 All Portal	TopoBathy Elevation Tinted Hillshad	de Imager
Living Atlas	📓 Elevation Coverage Map	Map Irr
🔺 [Computer	-	→ * *
🧰 Desktop 💂	Find more items	
Nam	e Ground Surface Elevatic Default	Ŧ
	C	DK Cancel

Click OK. You should see a gray "Ground Surface Elevation – 30 m" layer appear on the map.

This data could also have been downloaded from the National Map viewer,

<u>http://viewer.nationalmap.gov/viewer/</u>, although the process is a bit more tedious. Here we are saving time taking advantage of the Living Atlas data services.

Your map should look similar to the following:



Save your **Project** document if you have not already.

Let's export data from this DEM to have a local copy to work with. First we need to define the area that we want to work with. Let's pick an area that has a 2000 m buffer around the basin.

In the Geoprocessing Panel, use the search box to search on "buffer" and select the **Buffer (Analysis)** tool.



Set the inputs as follows and **Run** the tool.

Geoprocessing		→ ₽	×
\odot	Buf	fer (-	Đ
Parameters Environments		G	D
Input Features Watershed		• 🚘 🦯 •	,
Output Feature Class sisExercise\BasemapExercise.g	gdb\Lit	tleBearLogan\WatershedBuffer	,
Distance [value or field]		Linear Unit	•
	2000	Meters •	•
Side Type			
Full		•	,
Method			_
Planar		•	,
Dissolve Type			_
No Dissolve		•	-

Note that I saved the result in the BasemapExercise.gdb LittleBearLogan feature dataset.

The result should be a polygon that is 2000 m larger around the edge of the basin. If necessary, use the Symbology tool to change the Buffer symbology to an **Outline** and then you can see the other feature classes underneath it.



Use the search box to search on "clip" and select the **Clip Raster (Data Management)** tool. This tool was chosen because one of its allowable inputs is an image service.



	-	Geoprocessir	ng	≁ Ū ×
		©	Clip	2
Clip (Data Management Tools)	×	Parameters	Environments	?
Cuts out a portion of a raster dataset, mosaic dataset, or image service layer.		* Input Raster		• 🚍
		Output Extent		
clip				•
		Rectangle	-	R.
the state of the s		+	†	
		* Output Raster	Dataset	
		NoData Value		

Set the inputs as follows (setting the output to go into SpatialAnalysisExercise.gdb) and Run the tool.

Geoprocessing	≁ Ū ×
Clip Raster	\oplus
Parameters Environments	?
Input Raster	
Ground Surface Elevation - 30m	- 🧰
Output Extent	
WatershedBuffer	- 🧰
Rectangle	Ð
← -1258668.86564229 → -1190537.20611139	
↓ 257585.573918415	
Use Input Features for Clipping Geometry	
Output Raster Dataset	
$ISWork\SpatialAnalysisExercise\SpatialAnalysisExercise.gdb\IbId$	em 🧰
NoData Value	
-3.402823e+38	
Maintain Clipping Extent	

You should have a raster layer added to your ArcMap with a local subset from the DEM, that has the extent of WatershedBuffer and is easier to symbolize. Turn off the Ground Surface Elevation layers to see this display.



Note the skew appearance of the DEM lbldem just extracted. If you examine the **Layer Properties** for **Source ->Raster Information** for this you will see that it has a cell size of 30.92 m and in Spatial Reference **North America Albers Equal Area Conic** coordinate system. This is the resolution and coordinate system of the data as obtained from the ArcGIS elevation image service. This coordinate system is appropriate for display for all of North America and is skewed at the longitude of our area.

Let's add precipitation gages.

Select Add data and add LittleBearLoganAnnPrecip.csv.

Use Display XY Data on the table added to open the XY Table to Point tool and save the output feature class as PrecipGages in the LittleBearLogan feature dataset.

Geoprocess	sing	- џ ×
$ \in $	XY Table To Point	\oplus
Parameters	Environments	?
Input Table LittleBearLo	gan Ann Precip.csv	• 🚘
Output Feat	ure Class sise\BasemapExercise.gdb LittleBearLogan\PrecipGag	es
X Field Longitude		•
Y Field		
Latitude		•
Z Field		•
Coordinate S	System	
GCS_WGS_1	1984	•

This should add precipitation gages to the map. Symbolize them as you like.



2. Projecting the DEM

It is desirable to work with data in consistent coordinate systems. Let's project this DEM into the same projection as the LittleBearLogan Feature dataset (as we noted above the DEM from the web service was in a different coordinate system). Open the Toolboxes and open the tool **Data Management Tools** \rightarrow **Projections and Transformations** \rightarrow **Raster** \rightarrow **Project Raster**. If you find this tool hard to locate,

Projections and Transformations
🔺 🚔 Raster
🔨 Flip
🔨 Mirror
🔨 Project Raster

you can also search for it:

Geoprocessing	↓ 中 >
(project raster	× - =
Search Results (82)	
Project Raster (Data Management Tools)	

Set the inputs as follows to produce a projected raster **IbIdemproj** in SpatialAnalysisExercise.gdb geodatabase with **30m** cells and the **NAD 1983 UTM Zone 12** coordinate system used for the basemap. Note that the **NAD 1983 UTM Zone 12** coordinate system is most easily set by clicking next to Output Coordinate System and selecting from existing Layers on the map.

Geoprocessing		⊸ ₽ ×	Coordinate System		
\odot	Project Raster	\oplus	Select the Coordinate System to Current XY	o view the available opti Details Curr	ions. rent Z
Parameters Envir	onments	?	NAD 1983 UTM Zon	e 12N	<none></none>
Input Raster Ibldem			XY Coordinate Systems Av	railable Search	۳ م
Output Raster Data ork\SpatialAnalysi Output Coordinate NAD_1983_UTM_2 Geographic Transfo	aset isExercise\SpatialAnalysisExercise.gdb\ll e System Zone_12N prmation	bldemproj 📻	 Lavers MAD 1983 UTM Zo Worth America Albo WGS 1984 Web Me Geographic coordinate system Projected coordinate system 	ne 12N ers Equal Area Conic ercator Auxiliary Sphere item m	
Resampling Techni Bilinear interpolat Output Cell Size	ique ion	-			OK
X Registration Point	30 Y	30			
X	Y				

The result should appear similar to:



The spatial information about **IbIdemproj** can be found by right clicking on the ProjDEM layer, then clicking on **Properties** \rightarrow **Source** \rightarrow **Raster Information**, and **Statistics**

eneral	✓ Ra	ster Infor	mation						
1etadata	C	Columns			9				
ource	R	Rows			4				
levation	N	umber of Ba	inds	1					
isplay	Ce	ell Size X		30					
Cache	Ce	ell Size Y		30					
oins	U	ncompresse	d Size	37.3	6 MB				
Relates	Fo	ormat		FGD	BR				
	Sc	Source Type			ation				
	Pi	xel Type		floating point					
	Pi	Pixel Depth			32 Bit				
	N	NoData Value							
	C	olormap		absent					
	Py	ramids		level: 5, resampling: Nearest Neighbor					
	Co	ompression		LZ77	7				
	M	ensuration	Capabilities	Basi	c				
	> Ba	nd Metad	ata						
	✓ Sta	atistics							
	Bu	ild Parame	ters: skipped	colu	mns: 1, rows: 1, i	gnored value(s):			
	В	and Name	Minimum		Maximum	Mean	Std. Deviation		
	В	Band_1 1281.7877197		9726	3036.08203125	1918.643196447	422.4909835878		

To turn in: The number of columns and rows in the projected DEM. The cell size of the projected DEM. The minimum and maximum elevations in the projected DEM.

3. Exploring the DEM

Change the symbology of the lbldemproj layer.



To explore the highest elevation areas in your DEM select **Spatial Analyst Tools** \rightarrow **Map Algebra** \rightarrow **Raster Calculator**.



Double click on the **IbIdemproj** layer with the DEM for this area. Click on the greater than ">" symbol and select a number less than the maximum elevation. This arithmetic raster operation will select all cells with values above the defined threshold. In the example below a threshold of 3000 m was used.

Geoprocessing	↓ ↓ >					
Raster Calculator						
Parameters Environments	(?					
Map Algebra expression Rasters	🧀 Tools 🍸					
📙 lbldemproj	==					
📙 lbldem	>					
🦲 Ground Surface Elevatio	- 30m <					
	<=					
	>=					
"lbldemproj" > 3000						
Output raster	\$					
demgt3000						

A new layer appears on your map. The majority of the map (brown color in the figure below) has a 0 value representing false (values below the threshold), and the purple region has a value of 1 representing true (elevations higher than 3000 meters). If necessary, change the symbology of the resulting map display so that you can see high elevation areas more clearly and zoom in on them.



Use the raster calculator again (with elevation 3030 meter threshold) and the explore tool to identify the grid cell of maximum elevation in **Ibldemproj**. Take a screen shot similar to the below and indicate the grid cell with the highest elevation



Note that the above label was placed on the screen shot using a word processor. This is a bit easier than fiddling with labels in ArcGIS.

To turn in: A screen shot showing the location of the highest elevation value in the Little Bear Logan DEM.

4. Contours and Hillshade

Contours are a useful way to visualize topography. Select **Spatial Analyst Tools** \rightarrow **Surface** \rightarrow **Contour**. Select the inputs as follows, with a 10m contour interval:

Geoproces	sing		→ ₽ ×
\odot	Cont	our	\oplus
Parameters	Environments		?
Input raster			
Ibldemproj			- 📄
Output feat	ure class		
Contours			
Contour int	erval		50
Base contou	ır		0
Z factor			1
Contour typ	e		
Contour			•
Maximum v	ertices per feature		

A layer is generated with the topographic contours for Little Bear Logan area. Notice the big difference in Terrain Relief in Cache valley to the west and Bear River Range to the east.



Another option to provide a nice visualization of topography is Hillshading.

Select **Spatial Analyst Tools** \rightarrow **Surface** \rightarrow **Hillshade** and set the factor Z to a higher value to get a dramatic effect and leave the other parameters at their defaults (the following hillshade is produced with a Z factor of 10). Click OK. You should see an illuminated hillshaded view of the topography.

Geoprocessing		≁ ₽ ×
€ Hil	llshade	\oplus
Parameters Environments	5	?
Input raster		
Ibldemproj		-
Output raster		
Hillshade		
Azimuth		315
Altitude		45
Model shadows		
Z factor		1



To turn in: A layout with a depiction of topography either with elevation, contour <u>or</u> hillshade in nice colors. Include the streams from NHDPlus and watershed and sub-watersheds from the BasemapExercise.gdb LittleBearLogan feature dataset.

5. Zonal Average Calculations

In hydrology it is often necessary to obtain average properties over watersheds or subwatersheds. The Zonal functions in Spatial Analyst are useful for this purpose. Let's do this at the HUC10 watershed scale.

Locate the Dissolve Geoprocessing tool and set the inputs as follows

Geoprocessing • 4								
Disso	lve 🕀							
Parameters Environments								
Input Features								
Subwatersheds	- 🦯 -							
Output Feature Class								
asemapExercise.gdb\LittleBearL	.ogan\huc10watersheds 📄							
Dissolve Field(s) 📀								
HUC10	•							
	•							
Statistics Field(s)								
Field 😔 S	tatistic Type							
	•							
✓ Create multipart features								
Unsplit lines								

The resulting feature class has 4 features

	🛄 huc10watersheds 🗙										
Field: 📰 Add 🕎 Delete 🔄 Calculate 🛛 Selection: 🚭 Zoom To 🔮 Swi											
⊿	OBJECTID	Shape	HUC10	Shape_Length	Shape_Area						
	1	Polygon	1601020301	143516.329307	562295332.404097						
	2	Polygon	1601020302	167937.734998	742766372.217383						
	3	Polygon	1601020303	172341.610482	646088951.880712						
	4	Polygon	1601020304	115612.695643	337013525.957088						



Select Spatial Analyst Tools \rightarrow Zonal \rightarrow Zonal Statistics as Table. Set the inputs as follows:

Geoprocessing 🔹							
\odot	\oplus						
Parameters	Environments	?					
Input raster o	r feature zone data						
huc10waters	heds	- 🧀 🦯 -					
Zone field							
HUC10		-					
Input value ra	aster						
Ibldemproj		• 🚘					
Output table							
zoneelev							
✓ Ignore No	Data in calculations						
Statistics type	2						
All		-					

Click OK. A table with zonal statistics is evaluated and added to the map (at the bottom of the map display). Right-click to **open** the table.

	🗰 huc10watersheds 🛛 🔠 zoneelev 🗡									
Field: 📰 Add 🕎 Delete 🕎 Calculate Selection: 🖓 Zoom To 🚏 Switch 📄 Clear 💭 Delete 📄 Copy										
4	OBJECTID	HUC10	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
	1	1601020301	624780	562302000	1417.584106	2868.670898	1451.086792	1988.630832	316.915465	1242456771.074463
	2	1601020302	825283	742754700	1362.995483	2820.20874	1457.213257	2147.82101	277.664036	1772560166.357666
	3	1601020303	717908	646117200	1344.411987	3027.474121	1683.062134	2232.123414	367.636035	1602459255.904297
	4	1601020304	374475	337027500	1342.147949	2849.236084	1507.088135	1533.967219	276.361859	574432374.510498
	65 L									

This contains statistics of the value raster, in this case elevation from **IbIdemproj** over the zones defined by the polygon feature class **huc10watersheds**. The HUC10 field in this zone table may be used to join these values with attributes of the huc10watersheds feature class.

✓ huc10watersheds	and the second sec	
✓ Watershed	Copy Copy Remove Group	T Sturn BLUE
✓ Subwatersheds	Attribute Table	HANSEL VALLEY
Contours	Design	· · · · ·
▲	Create Chart	· / / //
▲ □ WatershedBuffer	Joins and Relates	• 🖽 Add Join

Right click on huc10watersheds and select Joins and Relates \rightarrow Add Join.

Select HUC10 as the field in this layer (huc10watersheds) that the join will be based on, zoneelev as the table to join to this layer, and HUC10 again as the field in the table to base the join on.

Geoproces	sing	≁ Ū ×						
\odot	Add Join	\oplus						
Parameters	Environments	?						
Layer Name	e or Table View							
huc10wate	huc10watersheds							
🥼 Input Join F	ield							
HUC10		•						
Join Table								
zoneelev		- 🧁						
Output Join	Field							
HUC10		•						
Keep All	Target Features							

Note the warning, which states: "The join field HUC10 in the join table huc10watersheds is not indexed. To improve performance, we recommend that an index be created for the join field in the join table."

This warning can be ignored for this particular dataset because this table is sufficiently small, so the presence of indices to speed up the data queries does not make any noticeable difference.

Open the huc10watersheds attribute table and scroll across. You'll see the statistics have been added to the attributes that this feature class already held.

	🖩 huc10watersheds × 🖽 zoneelev															
Fi	Field: 🕅 Add 👼 Delete 🗃 Calculate 🛛 Selection: 🤤 Zoom To 🚏 Switch 📄 Clear 💭 Delete 🚔 Copy															
	OBJECTID	Shape	HUC10	Shape_Length	Shape_Area	OBJECTID	HUC10	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	
	1	Polygon	1601020301	143516.329307	562295332.404097	1	1601020301	624780	562302000	1417.584106	2868.670898	1451.086792	1988.630832	316.915465	1242456771.074463	
	2	Polygon	1601020302	167937.734998	742766372.217383	2	1601020302	825283	742754700	1362.995483	2820.20874	1457.213257	2147.82101	277.664036	1772560166.357666	
	3	Polygon	1601020303	172341.610482	646088951.880712	3	1601020303	717908	646117200	1344.411987	3027.474121	1683.062134	2232.123414	367.636035	1602459255.904297	
	4	Polygon	1601020304	115612.695643	337013525.957088	4	1601020304	374475	337027500	1342.147949	2849.236084	1507.088135	1533.967219	276.361859	574432374.510498	
	Click to add	new row														

In the Geoprocessing panel, select Table to Excel and specify Subwatershed as the input Table, and SubwatershedStats as output Excel file.

Geoprocessing	→ ₽ >	Geoprocessing -	Ψ×
table to excel	× • Ξ	E Table To Excel	\oplus
Table To Excel (Conversion Tools)		Parameters Environments	?
		Input Table huc10watersheds Output Excel File (.xls or .xlsx) Its\ArcGISWork\SpatialAnalysisExercise\huc10stats.xlsx Use field alias as column header	

If you open up the resulting huc10stats Excel file you'll see the descriptive statistics there for these huc10 watersheds.

Determine the mean elevation and elevation range of each huc10 watersheds in the Little Bear Logan subbasin.

To turn in: A table giving the HUC10, mean elevation, and elevation range for each watershed in the huc10 watersheds feature class. Which watershed has the highest mean elevation? Which watershed has the largest elevation range?

6. Calculation of Area Average Precipitation using Thiessen Polygons

Now to do something really useful. We will calculate the area average mean annual precipitation over the watershed using Thiessen polygons. Thiessen polygons associate each point in a watershed with the nearest raingage. Let's do this for watersheds draining to each stream gage.

In the geoprocessing panel locate the Watershed tool in Ready to Use Tools under Portal



Set input points as Gages and Data Source Resolution FINEST.

Geoprocessing	≁ ∏ ×	
\odot	Watershed	\oplus
Parameters En	vironments	?
Input Points Gages Point Identificat Snap Distance	ion Field	• 🚔 🖊
Snap Distance U Meters	nits	
Data Source Res FINEST Generalize W	olution /atershed Polygons ped Points	•

Click Run. Three watersheds should be delineated.



It may be that you are not able to do this due to this function using ESRI cloud credits that may not have been assigned to your account. You may need to work with your university instructor and ESRI site license manager to get this capability for your ESRI account.

Alternatively, you may do this for the HUC10 watersheds, instead of delineated watersheds.

Right Click on OutputWatershed from the Watershed delineation and select Data -> Export Features to open the Feature Class to Feature Class tool. Name the result gagewatersheds and put it in the LittleBearLogan feature dataset.

Geoprocessing	- ₽ ×
	\oplus
Parameters Environments	?
Input Features Output Watershed	/-
Output Location AnalysisExercise\BasemapExercise.gdb\LittleBearLog	jan 🧀
Output Feature Class gagewatersheds	
Expression	

Turn on the **PrecipGages** layer in the map display and open their attribute table. You'll see an **AnnPrecip** attribute which is the mean annual precipitation at each gage in mm.

Fie	Field: 🕅 Add 📆 Delete 🕎 Calculate 🛛 Selection: 🕀 Zoom To 🚏 Switch 📄 Clear 💭 Delete 🖶 Copy												
⊿	OBJECTID	Shape	SiteName	SiteCode	FullSiteCo	Latitude	Longitude	Elevation	d1	d2	nd	nme	annprecip
	1	Point	BEAR LAKE SP	USC00420487	GHCN:USC00420487	41.9583	-111.3922	1806.9	1/1/1989	6/30/2017	10407	29	347.359211
	2	Point	BRIGHAM CITY WAS	USC00420928	GHCN:USC00420928	41.5239	-112.0436	1289.3	1/1/1974	6/30/2017	15886	323	399.520186
	3	Point	CUTLER DAM	USC00421918	GHCN:USC00421918	41.8328	-112.0558	1307.6	1/1/1980	6/30/2017	13695	32	427.072792
	4	Point	HUNTSVILLE MONAS	USC00424135	GHCN:USC00424135	41.2403	-111.7131	1566.7	1/1/1976	12/31/2013	13879	273	551.386765
	5	Point	LAKETOWN	USC00424856	GHCN:USC00424856	41.825	-111.3208	1822.7	1/1/1900	6/30/2017	42914	32	370.666283
	6	Point	LOGAN RADIO KVNU	USC00425182	GHCN:USC00425182	41.735	-111.8564	1364	1/1/1956	6/30/2017	22461	322	426.836988
	7	Point	LOGAN UTAH ST UNIV	USC00425186	GHCN:USC00425186	41.7456	-111.8033	1460	1/1/1893	6/30/2017	45470	311	493.154006

Select the tool Analysis Tools → Proximity → Create Thiessen Polygons



Specify **PrecipGages** as the Input Features. Save the output feature class in the LittleBearLogan feature dataset and indicate that **ALL** fields should be output. By saving to the LittleBearLogan feature dataset you ensure that the Thiessen polygon feature class inherits the spatial reference information from this feature dataset, keeping all your work in a consistent spatial reference. Click OK. It's really important that you select "All" here to carry the attributes of the Precipitation stations to the polygons associated with them.

Geoprocess	sing	≁ Ū ×
	Create Thiessen Polygons	\oplus
Parameters	Environments	?
Input Feature PrecipGage Output Feature thiessenpol	es s ure Class v	• • /•
Output Field All fields	s	—

Switch to Environments and for Extent select Watershed

Geoprocessing										
Create T	hiessen Polygons 🕀									
Parameters Environme	ents (?)									
Output Coordinate System Geographic Transformations										
(i) Extent	As Specified Below									
← 412486.689	As Specified Below									
4579982.6082	Browse									
Output XY Domain Output M Domain Output Z Domain	Same As layer: Output Snapped Points PrecipGages Gages									
XY Tolerance	Watershed thiessenpoly									

This is important to avoid the polygons not completely covering the watersheds being used.

The result is a Thiessen polygon feature class. This tessellates the landscape into regions that are closer to a particular gage than to any other.



Here is what your attribute table should look like for thiessen polygons. If it doesn't have all these attributes at the right hand end, delete the result you just computed and do it over with the ALL option selected to make sure you transfer all the attributes from the gages to the polygons.

Field:	iled: 🕅 Add 🕅 Delete 🗐 Calculate 🛛 Selection: 🝭 Zoom To 🔮 Switch 📄 Clear 💭 Delete 📄 Copy															
	BJECTID	Shape	Shape_Length	Shape_Area	Input_FID	SiteName	SiteCode	FullSiteCo	Latitude	Longitude	Elevation	d1	d2	nd	nmo	annprecip
1		Polygon	40000.767462	93490066.044634	16	Ben Lomond Peak	USS0011H08S	GHCN:USS0011H08S	41.38	-111.94	2438.4	1/1/1978	6/30/2017	14425	330	1458.708777
2		Polygon	80658.171802	378789146.855697	23	Monte Cristo	USS0011H57S	GHCN:USS0011H57S	41.47	-111.5	2731	1/1/1978	6/30/2017	14425	327	993.26627
3		Polygon	71337.626833	342119071.543406	18	Little Bear	USS0011H25S	GHCN:USS0011H25S	41.41	-111.83	1994.6	1/1/1978	6/30/2017	14425	327	875.193497
4		Polygon	32124.462381	39419189.51191	19	Ben Lomond Trail	USS0011H30S	GHCN:USS0011H30S	41.38	-111.92	1776.7	1/1/1980	6/30/2017	13695	327	1059.625324
5		Polygon	62649.243508	198295801.291669	2	BRIGHAM CITY WAS	USC00420928	GHCN:USC00420928	41.5239	-112.0436	1289.3	1/1/1974	6/30/2017	15886	323	399.520186
6		Polygon	67870.409471	207292640.501138	22	Dry Bread Pond	USS0011H55S	GHCN:USS0011H55S	41.41	-111.54	2545.1	1/1/1978	6/30/2017	14425	330	783.452703
7		Polygon	77926.567362	323109363.206263	20	Tony Grove Lake	USS0011H36S	GHCN:USS0011H36S	41.9	-111.63	2582.9	1/1/1978	6/30/2017	14425	327	1222.911655

If you rearrange the map display you can get a map looking something like the below. What we're going to do is to find the area of each thiessen polygon that overlays each gagewatershed. This is done using the **Intersect** function, one of the most powerful functions of spatial analysis.



To average precipitation values in these polygons over the subwatersheds we need to intersect the thiessen polygons with the gage watersheds and compute area weighted averages for each subwatershed. The following calculations achieve this.

Use the search window to locate the Intersect (Analysis) tool and set the inputs as follows

Geop	processing	* † ×
	Intersect	\oplus
Paran	neters Environments	?
Inpu	It Features 📀 🛛 🛛 Ranks	
	gagewatersheds 🔹 🧰	
	thiessenpoly 🔹 🚘	
Outp	put Feature Class	
napl	Exercise.gdb\LittleBearLogan\thiessen_ws_inter	sect 🦳
Attri	ibutes To Join	
All	attributes	-
XY T	olerance	
	Meters	•
Outp	put Type	
San	ne as input	•

Following is the result, the thiessen_ws_intersect polygons symbolized with **SiteCode** as the Unique Value field – this is the identifying code of the rain gage in the Global Historical Climate Network (GHCN).



If you open the ThiessenSubIntersect attributed table you will see that from the 3 subwatersheds there are now 14 polygons, each contributing to part of a subwatershed and associated with a single rain gage. Let P_k denote the precipitation associated with each rain gage and A_{ik} the area of intersected polygon associated with rain gage k and subwatershed i. Then the area weighted precipitation associated with each subwatershed is

$$P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}}$$

Open the attribute table for the intersected thiessen polygons and add a new field to the table, **APProd**.



Double-click on the greyed-out "Data Type" column, where it says Long, and change the Data Type of APProd to **Float**. If you don't change this data type, your calculations will fail on a datatype mismatch error.

	huc10water	sheds 🔠 :	zoneelev 🛛	🖩 Gages	📰 PrecipGages		thiessenpoly	💷 thiessen_ws	_intersect 🛛 🖷	Fie
Cu	rrent Layer	thiessen_	ws_intersect	*]		_			
⊿	✓ Visible	Read Only	Field Name	Alias		Short	Allow NULL	Highlight	Number Format	D
	\checkmark		d2	d2	ſ	Float				
	\checkmark		nd	nd	L	Double	~		Numeric	
	\checkmark		nmo	nmo		Date			Numeric	
	\checkmark		annprecip	annpre	ecip	Text	\checkmark		Numeric	
	\checkmark	\checkmark	Shape_Length	Shape_	_Length	Blob Guid	V		Numeric	
	\checkmark	~	Shape_Area	Shape_	_Area	Raster	~		Numeric	
	\checkmark		APProd		l	ong	· 🗸			

Make sure to save your changes using the save button in the **Fields** tab at the top of the screen.



Go back to the thiessen_sub_intersect polygon attribute table and right-click on the header of APProd, selecting "Calculate Field".

III thiessen_sub_intersect X III Fields: thiessen_sub_intersect 🗸													
Field: 🖩 New 👼 Delete 🗐 Calculate Selection: 🖓 Zoom To 🖓 Switch 🖸 Clear 🗙 Delete 🔳													
⊿iessenpoly	Input_FID	COOPID	stname	latdd	longdd	ELEVATION	ELEM	Nyr	AnnPrecip_in	Shape_Length	Shape_Area	APProd	
5	2	410429	AUSTIN-BERGSTRO	30.183333	-97.683333	146.3	ТРСР	6	34.515	51277.895967	77596679.322343	≺Nul Ž	Sort <u>A</u> scending
6	32	419815	WIMBERLEY 1 NW	30	-98.066667	253	ТРСР	21	40.47619	34427.447989	44918977.209083	≺Nul A	Sort <u>D</u> escending
18	22	415285	LOCKHART 2 SW	29.85	-97.7	149.4	ТРСР	10	36.125	67155.210013	168254343.46856	<nul td="" 💲<=""><td><u>C</u>ustom Sort</td></nul>	<u>C</u> ustom Sort
6	32	419815	WIMBERLEY 1 NW	30	-98.066667	253	ТРСР	21	40.47619	66821.259515	120874333.043417	<nu td="" 🚌<=""><td>Calculate Field</td></nu>	Calculate Field
7	28	418358	SISTERDALE	20 083333	-98 733333	426.7	трср	11	40 497273	31014 844286	33314467 803939	< Nut	Concentration

Create the expression **!annprecip! * !Shape_Area!** and click Run.

Geoprocessing	т ф ×
Calculate Field	\oplus
Parameters Environments	?
Input Table thiessen ws intersect	•
Field Name	
Expression Type Python 3 Expression	•
Fields T Helpers	T
d1 d2 nd nmo annprecip Shape_Length Shape_Area APProd Insert Values * / + - =	V
<pre>!annprecip! * !Shape_Area!</pre>	Å T

The result is a new field with the numerator terms for the equation above. Now locate the column Pour Point ID. These are unique identifiers for each gage watersheds (1, 2, 3 assigned during their creation). Right click on the header and select Summarize

	an a			Calcul Statisti Summ	ate Geometry ics arize	
	I Gages	F		Fields		
te	Selection:			D. L.	Summary T	able
ds	Pour Point I	D	± D	Delete	the current	mmary ta field. If ai
1		1	NE	ED 30m	currently se rows will be	lected, or calculate
1		1	NE	ED 30m	processed	30.0
1		1	NE	ED 30m	processed	30.0
1		1	NE	ED 30m	processed	30.0
1		1	NE	ED 30m	processed	30.0
2		2	NE	ED 30m	processed	30.0
n		h	NIE	C		20.0

Carefully select the summary statistics you need. I selected the following: Pout Point ID - First, Shape_Area - Sum, APProd – Sum, and the Pout Point ID Case field. Click Run.

Geoprocessi	ıg	≁ ₽ ×				
\odot	Summary Statistics					
Parameters E	?					
Input Table						
thiessen_ws_i	ntersect	- 🧎				
Output Table						
thiessen_state						
Statistics Field Field 💎	s) Statistic Type					
Pour Poir	t ID 🔻 First	•				
Shape_Ar	ea 🔹 Sum	•				
APProd	▼ Sum	•				
Case field 😔	•	•				
Pour Poir	t ID	•				
		•				

Navigate to your output table, and you'll see that the resulting table gives the numerator and denominator in the equation above for each subwatershed.

	iii huc10watersheds iii zoneelev iii thiessen_stats ×									
Field: 📰 Add 🕎 Delete 📰 Calculate 🛛 Selection: 🕂 Zoom To 📲 Switch 📃 Clear 💭 Delet										
	OBJECTID	Pour Point ID	FREQUENCY	FIRST_PourPtID	SUM_Shape_Area	SUM_APProd				
	1	1	5	1	517253854.778151	404967735808				
	2	2	5	2	679242847.138664	540768213504				
	3	3	4	3	555011142.085791	553897109504				
	Click to add new row.									

	🖩 huc10watersheds 🛛 zoneelev 🕮 thiessen_stats 🖓 🖷 Fields: thiessen_stats 🗡							
Cu	Current Layer thiessen_stats							
⊿	✓ Visible	Read Only	Field Name	Alias	Data Type	Allow NULL	Highlight	Number Form
	\checkmark	\checkmark	OBJECTID	OBJECTID	Object ID			Numeric
	\checkmark		PourPtID	Pour Point ID	Long	V		Numeric
	\checkmark		FREQUENCY	FREQUENCY	Long	1		Numeric
	\checkmark		FIRST_PourPtID	FIRST_PourPtID	Long	\checkmark		Numeric
	\checkmark		SUM_Shape_Area	SUM_Shape_Area	Double	\checkmark		Numeric
	\checkmark		SUM APProd	SUM APProd	Double	V		Numeric
	\checkmark		GageW_Precip_mm	GageW_Precip_mm	Float	\checkmark		Numeric

Add a New field GageW_Precip_mm to this table, again as a Float, and Save the result.

Go back to the thiessen_stats table and use **Calculate Field** to evaluate this as **!Sum_APProd! / !Sum_Shape_Area!. R**ight click on the top of the field to open Calculate Field.

Geoprocessing	* ἀ ×
€ Calc	ulate Field 🕀
Parameters Environmen	ts 🥐
Input Table	
thiessen_stats	- 🛁
Field Name	
GageW_Precip_mm	-
Expression Type	
Python 3	-
Expression	
Fields	T Helpers
OBJECTID	.conjugate()
Pour Point ID	.denominator()
FREQUENCY	.imag()
FIRST_PourPtID	.numerator()
SUM_Shape_Area	.real()
SUM_APProd	.as_integer_ratio()
GageW_Precip_mm	.fromhex()
	.hex()
Insert Values	* * / + - =
GageW_Precip_mm =	
!SUM_APProd! / !SUM	L_Shape_Area!
Code Block	Ť

The result is the precipitation in mm for each subwatershed. This is pretty cool! And you can see how the tools in ArcGIS can give you a spatially area-weighted result that would be more tedious to derive otherwise.

To turn in: A table giving the Pour Point Identifier, Name, and mean precipitation by the Thiessen method for each gage watershed. Determine the watershed names from their associated stream gages Which subwatershed has the highest mean precipitation?

7. Estimate basin average mean annual precipitation using Spatial Interpolation/Surface fitting

Thiessen polygons were effectively a way of defining a field based on discrete data, by associating with each point the precipitation at the nearest gage. This is probably the simplest and least sophisticated form of spatial interpolation. It also does not account for elevation adjustments. ArcGIS provides other spatial interpolation capabilities in both the Spatial Analyst and Geostatistical Analyst Toolboxes. Following are the interpolation tools in each.



We will not, in this exercise, concern ourselves too much with the theory behind each of these methods. You should however be aware that there is a lot of statistical theory on the subject of interpolation, which is an active area of research. This theory should be considered before practical use of these methods.

In preparing this exercise I experimented with Empirical Bayesian Kriging which is reported to be one of the most advanced of these. I found that it took a very long time to complete, however you are

welcome to try it with the following inputs. Use the input points from "PrecipStn" and Z value field as "AnnPrecip_in". Set the output cell size to 100 m to improve the spatial resolution.

Geoprocess	sing	≁ ų ×				
	Empirical Bayesian Kriging	\oplus				
Parameters	Environments	?				
Input feature	25					
PrecipGage	s	- 🧰				
Z value field						
annprecip		-				
Output geos	Output geostatistical layer					
Output raste	r					
emp_bk	emp_bk					
Output cell s	ize					
100						
Data transfo	rmation type					
None		-				
Semivariogra	am model type					
Power		-				
> Additional	Model Parameters					
Search Neig	Indorhood Parameters					

> Output Parameters

Also set extent to watershed to make sure the result covers the area you want.

Following is the result from Empirical Bayesian Kriging



Following are inputs for tension **Spline** interpolation (Spatial Analyst tools). Use the input points from **PrecipGages** and Z value field as **annprecip**, and set the spline type as **Tension** with parameters as follows. I reduced the output cell size to 100 m to improve the spatial resolution. The result follows:

Geoprocessing	≁ ₫ ×				
€ Spline					
Parameters Environments	?				
Input point features PrecipGages Z value field annprecip Output raster spline Output cell size 100	• 🖬				
Spline type Tension	•				
Weight	0.1				
Number of points					

This runs a lot faster and the result is smoother than Empirical Bayes Kriging.



Now, let's use Zonal Statistics to compute the average value of the spline precipitation map over each subwatershed. Select **Spatial Analyst Tools** \rightarrow **Zonal** \rightarrow **Zonal Statistics as Table**. Set the inputs as follows:

Geoproces	sing	≁ Ū ×
\odot	Zonal Statistics as Table	\oplus
Parameters	Environments	?
Input raster	or feature zone data	
gagewaters	heds	• 🧀 🦯 •
Zone field		
Pour Point	-	
Input value		
spline		-
Output table	e	
zonespline		
✓ Ignore N	oData in calculations	
Statistics typ	e	
All		-

Click Run. A table with zonal statistics is created. This contains statistics of the value raster, in this case mean annual precipitation from **Spline** over the zones defined by the polygon feature class **ggewatersheds**.

	🖽 huc10watersheds 🗰 zoneelev 🖽 thiessen_stats 🔠 zonespline ×										
Fi	Field: 📰 Add 🕎 Delete 🔄 Calculate Selection: 🚭 Zoom To 📲 Switch 📄 Clear 💭 Delete 🗐 Copy										
	OBJECTID	PourPtID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	Γ
	1	1	51723	517230000	506.085571	980.356689	474.271118	768.436626	76.505703	39745847.627899	Γ
	2	2	67928	679280000	581.322266	1014.800232	433.477966	781.416452	114.541129	53080056.766174	
	3	3	55523	555230000	526.560364	1275.653076	749.092712	1010.87846	238.608714	56127004.71051	
	Click to add new row										

The PourPtID in this table may be used to join it to the attribute table for the gagewatershed feature class. As for the elevations above this joined statistics table can be exported to Excel for formatting to prepare your turn in results.

To turn in: A table giving the Pour Pt ID, Name, and mean precipitation by the Tension Spline method for each gage watershed. Which subwatershed has the highest mean precipitation using a Tension Spline interpolation?

We will stop here. There are other things that would be interesting to do. I am going to list them for you to explore, but not make as part of the exercise as this is long already.

- 1. Use zonal statistics to determine the elevation of each rain gage. Cross check this against elevation from GHCN.
- 2. Develop a relationship between elevation and annual precipitation. We know that precipitation in this area is orographic, so a relationship is expected.
- 3. Use the elevation precipitation relationship to calculate a grid of precipitation estimated from elevation and average this over watersheds. Compare this to the area average watershed computed from spline interpolation or thiessen polygons that operate in the horizontal plane.
- 4. Examine annual steamflow at the stream gages that define watershed outlets. Convert this to depth (volume / area) and compare to precipitation depth. Streamflow depth/Precipitation depth is runoff ratio, and tells us the fraction of precipitation that manifests as streamflow.

Summary of Items to be Turned in:

- 1. The number of columns and rows in the projected DEM. The cell size of the projected DEM. The minimum and maximum elevations in the projected DEM.
- 2. A screen shot showing the location of the highest elevation value in the Little Bear Logan DEM.
- 3. A layout with a depiction of topography either with elevation, contour or hillshade in nice colors. Include the streams from NHDPlus and watershed and sub-watersheds from the BasemapExercise.gdb LittleBearLogan feature dataset.
- 4. A table giving the HUC10, mean elevation, and elevation range for each watershed in the huc10 watersheds feature class. Which watershed has the highest mean elevation? Which watershed has the largest elevation range?
- 5. A table giving the Pour Point Identifier, Name, and mean precipitation by the Thiessen method for each gage watershed. Determine the watershed names from their associated stream gages Which subwatershed has the highest mean precipitation?
- 6. A table giving the Pour Pt ID, Name, and mean precipitation by the Tension Spline method for each gage watershed. Which subwatershed has the highest mean precipitation using a Tension Spline interpolation?

Appendix.

This appendix describes the use of CUAHSI data services (<u>http://data.cuahsi.org/</u>) and the CUAHSI WaterML R package (<u>https://www.cuahsi.org/data-models/discovery-and-analysis/</u>) to assemble the data for this exercise. However there were some difficulties with the WaterML package for the GHCN service so I used the RNOAA package to actually get the data. The work done in preparing **LittleBearLoganAnnPrecip.csv** is detailed in **AssembleGHCNData.R**.

The steps followed were

- 1. Install necessary R packages.
- 2. Get list of CUAHSI data services using **GetServices**().

- 3. Identify which service is for the Global Historical Climatology Network. This has server http://hydroportal.cuahsi.org/ghcn/cuahsi_1_1.asmx?WSDL
- 4. Get list of sites from this server **GetSites(server)**
- 5. Output sites to a CSV file, import to ArcGIS to see where they are located.
- 6. Use a spatial query to select sites inside and within 20 km of Little Bear River subbasin boundary.
- 7. Read these local sites into R
- 8. Use **GetSiteInfo()** for each of these sites to identify the period of record of precipitation data.
- 9. Select only sites with more than 10 years of data
- 10. Use a NOAA data service **ncdc()** from RNOAA R package to download the data.
- 11. Use R to compute annual average precipitation for sites with sufficient data and write the results.